Module 2.1 Monitoring activity data for forests using remote sensing

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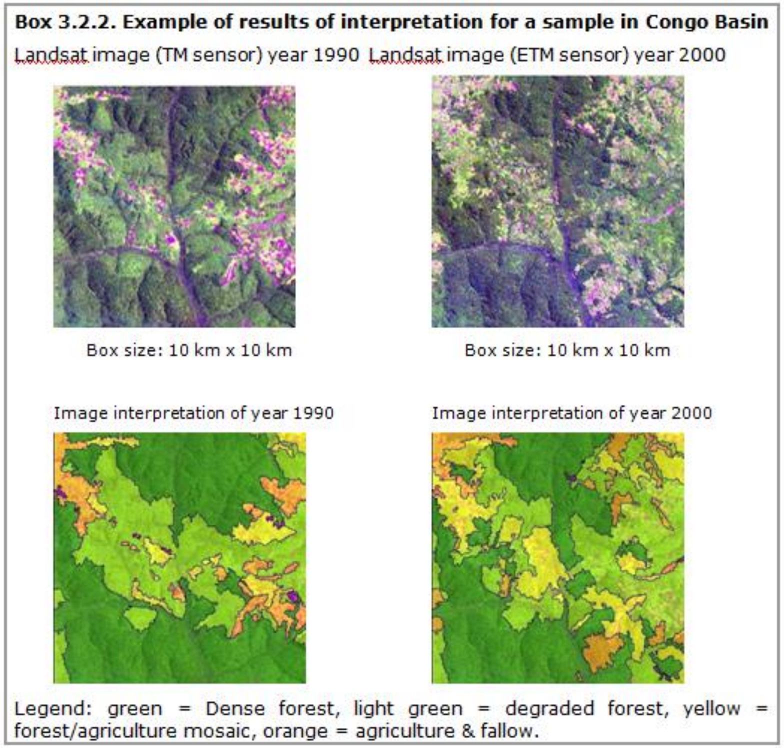
After the course the participants should be able to:

- Differentiate between different (remote sensing) approaches to monitor changes in forest areas
- Perform forest area change analysis using Landsat satellite data



Source: GOFC-GOLDSourcebook 2014, Box 3.2.2.

V1, May 2015

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GOFC-GOLD Global Observation of Forest and Land Cover Dynamics

FOREST CARBON PARTNERSHIP FACILITY

Background material

- GOFC-GOLD. 2015. *Sourcebook*. Sections 1.2, 2.1, 2.7, and 2.9. Section 3.2 for country examples.
- UNFCCC. 2011. Decision 1/CP16. The Cancun Agreements. http://unfccc.int/resource/docs/2010/cop16/eng/07a01.pdf#page=2
- IPCC. 2003. Good Practice Guidance for Land Use, Land-Use Change, and Forestry.
- GFOI. 2016. Integrating Remote-sensing and Ground-based Observations for Estimation of Emissions and Removals of Greenhouse Gases in Forests: Methods and Guidance from the Global Forest Observation Initiative (MGD). Sections 2.2.1 and 3.

Outline of lecture

1. Introduction
2. Selection of a monitoring approach
3. Image classification and analysis
4. Accuracy assessment
5. Limitations to using satellite data

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IPCC requirements for measuring and reporting of changes in forest area (1/2)

- The IPCC methodologies and UNFCCC reporting principles have been identified as the basis for the REDD+ activities
- IPCC methodologies aim for full, accurate, transparent, consistent, and comparable reporting of GHG emissions and removals (e.g., of changes in forest areas)
- Reporting also includes a detailed description of the used inventory approach and planned improvements

See Module 3.3 on reporting REDD+ performance.

IPCC requirements for measuring and reporting of changes in forest area (2/2)

- IPCC guidelines refer to two basic inputs with which to calculate greenhouse gas inventories: **activity data** and **emissions factors**.
- For activity data, spatially explicit land conversion information, derived from sampling or wall-to-wall mapping techniques, is encouraged.

Key role for earth observation in monitoring tropical forests

- Fundamental requirement of national monitoring systems are that they:
    i. Measure changes throughout all forested area
    ii. Use consistent methodologies at repeated intervals to obtain accurate results and
    iii. Verify results with ground-based or very high resolution observations
- The only practical solution to implement such monitoring systems in tropical countries often with low accessibility to forest areas is through interpretation of remotely sensed data supported by ground-based observations.

Issues affecting the selection and implementation of a monitoring approach

- Multiple approaches are appropriate and reliable for forest monitoring at national scales. Issues affecting the design of the monitoring system include, for example:
    I. National circumstances, particularly existing definitions and data sources

    II. Decision on change assessment approach, defined by:
        a. Satellite imagery
        b. Sampling versus wall-to-wall coverage
        c. Fully visual versus semi-automated interpretation
        d. Accuracy or consistency assessment

    III. Available resources:
        i. Hard- and software resources
        ii. Required training

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Required activity data

- Depending on national decisions on the approach to be used, the following types of maps may be useful for reporting on the changes in forest cover:
  - Forest/nonforest map (+ change maps)
  - National land-cover/land-use map (+ change maps)
  - Forest stratification
  - Map of changes within forest land (see Module 2.2)
- A monitoring approach suitable for producing the required activity data needs to be selected: a sample of reference data need to be used to produce accurate estimates

Forest definition (1/2)

- Currently Annex I parties use the UNFCCC definition of forest and deforestation adopted for implementation of Articles 3.3 and 3.4 of Kyoto protocol.
- FAO uses a minimum cover of 10%, height of 5 m and area of 0.5 ha, stating also that forest use should be the predominant land use in the area.
- For the Kyoto Protocol, parties should select a single value of crown area, tree height, and area within following ranges:
  - Minimum forest area: 0.05 to 1 ha
  - Potential to reach a minimum height at maturity *in situ* of 2–5 m
  - Minimum tree crown cover: 10–30 %

Forest definition (2/2)

- No agreement on a forest definition currently exists under REDD+.
- Countries can choose their own forest definition as long as they clearly describe the definition.
- Note that remote sensing imagery allows **land cover** to be observed; field information is needed to derive **land use.**

Designation of forest area

- Ideally, wall-to-wall assessments would be carried out to identify forested area according to UNFCCC forest definitions.
- Alternatively, existing forest maps for a relatively recent time could be used to identify the overall forest extent.

Important principles in identifying the forest extent:

- The area should include all forests within the national boundaries
- A consistent overall forest extent should be used for monitoring all forest changes during assessment period

Selection of satellite imagery

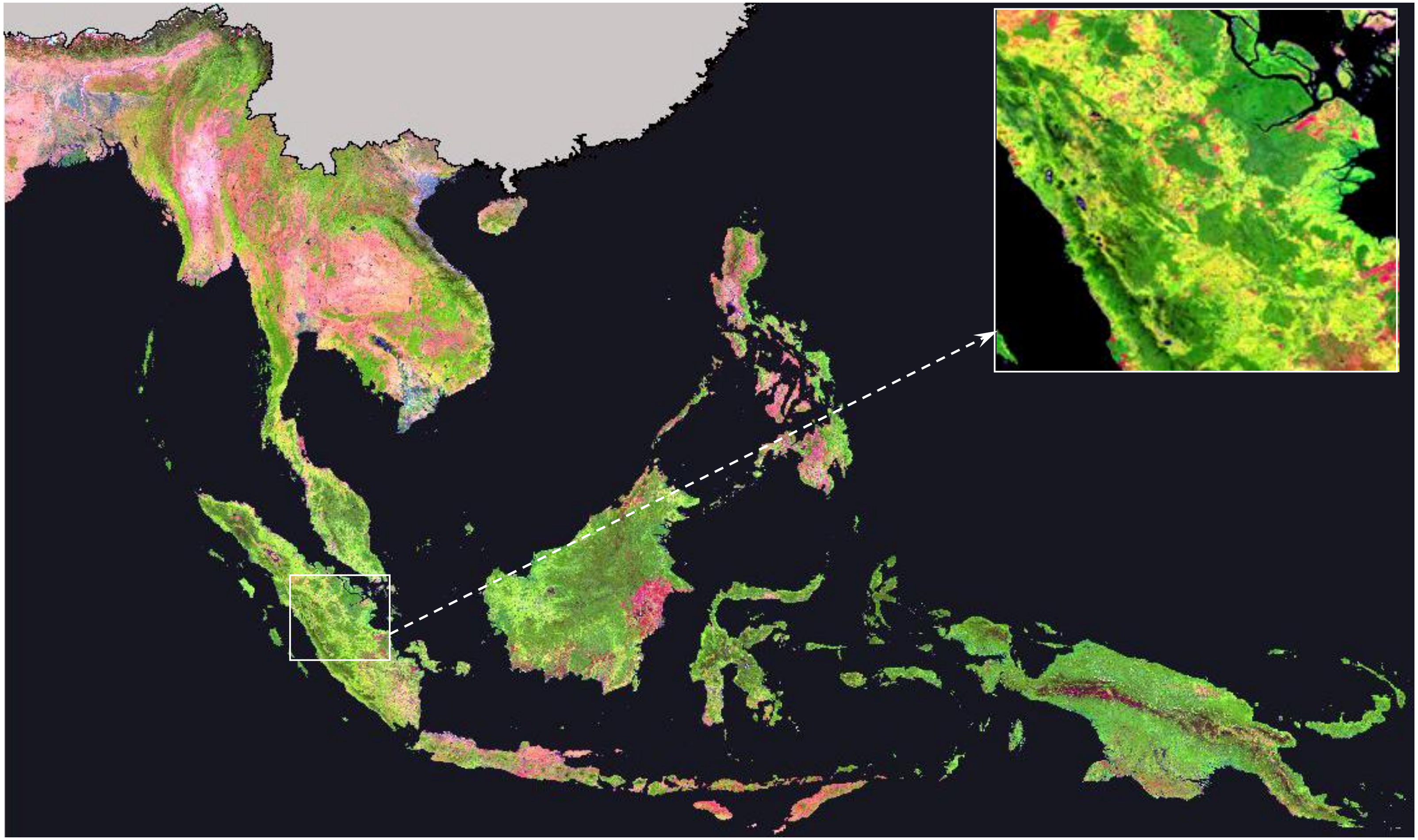
- Many different types of data from optical sensors at a variety of resolutions and costs are available for monitoring deforestation.
- The selection of the type of satellite data depends on national circumstances (forest types, size of the country, seasonality, available funds, etc.).
- The most commonly used types of satellite data for forest-cover monitoring are listed on the next slide with a summary of their usability for various purposes.

Utility of optical sensors at multiple resolutions for deforestation monitoring

Resolution	Examples of sensors	Minimum mapping unit (change)	Cost	Primary utility for deforestation monitoring
Coarse (250-1000 m)	SPOT-VGT Terra-MODIS Envisat-MERIS Suomi NPP - VIIRS	~ 100 ha ~ 10-20 ha	Low or free	Consistent pan-tropical annual monitoring to identify large clearings and locate "hotspots" for further analysis.
Medium (10-60 m)	Landsat TM, ETM+ and OLI Terra-ASTER IRS AWiFs or LISS III CBERS HRCCD DMC SPOT HRV ALOS AVNIR-2 Sentinel-2 MSI (2015→)	0.5 - 5 ha	Landsat & CBERS are free; for others: <$0.001/km² for historical data $0.02-0.5/km² for recent data	Primary tool to map deforestation and estimate forest area change.
Fine (<5 m)	RapidEye IKONOS QuickBird Aerial photos	< 0.1 ha	High to very high $2 -30 /km²	Validation of results from coarser resolution analysis, and training of algorithms.

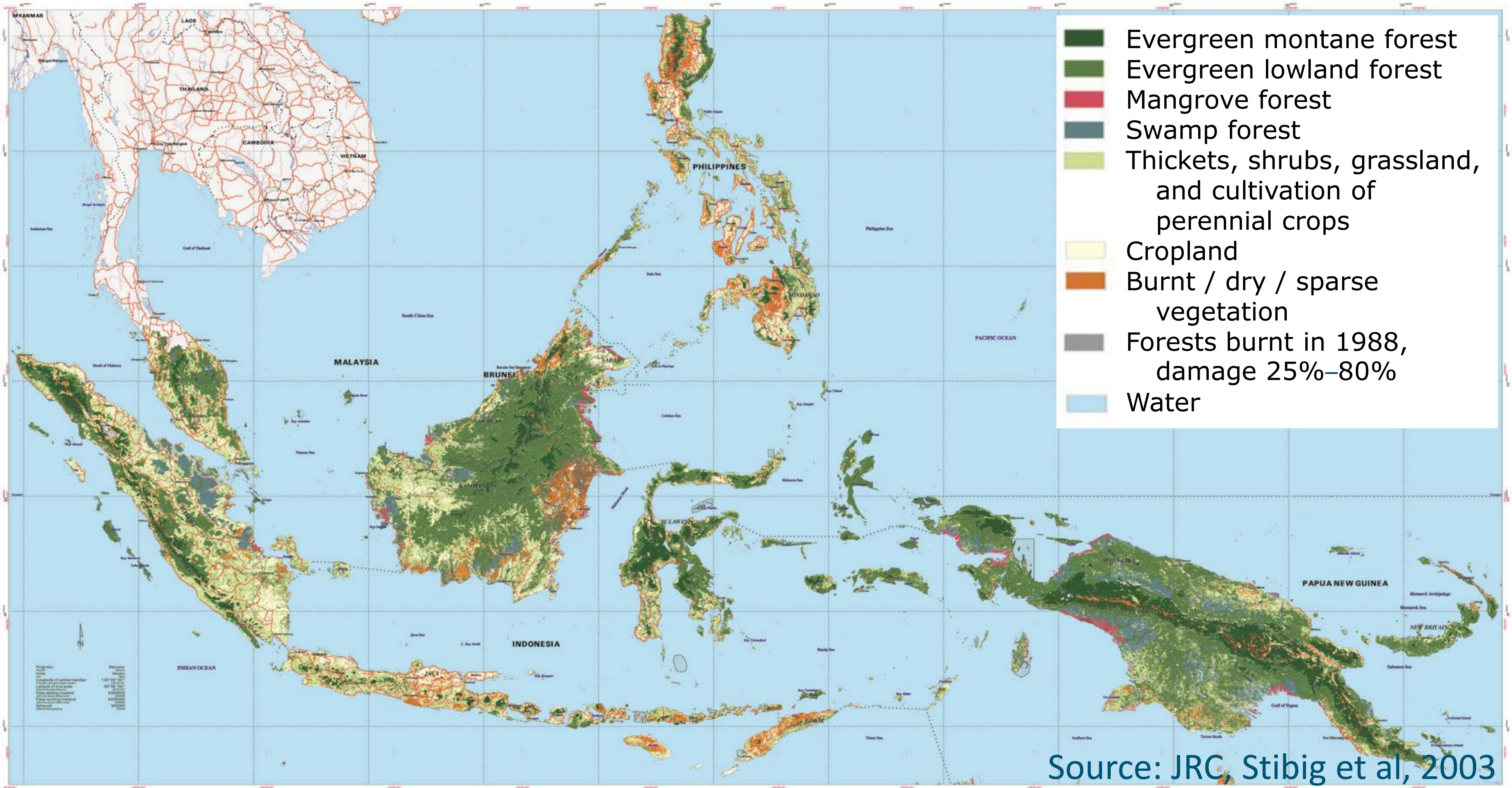
Source: GOFC GOLD Sourcebook 2014, table 2.1.1.

Example of a 1 km resolution SPOT VGT image composite for year 2000 covering Southeast Asia



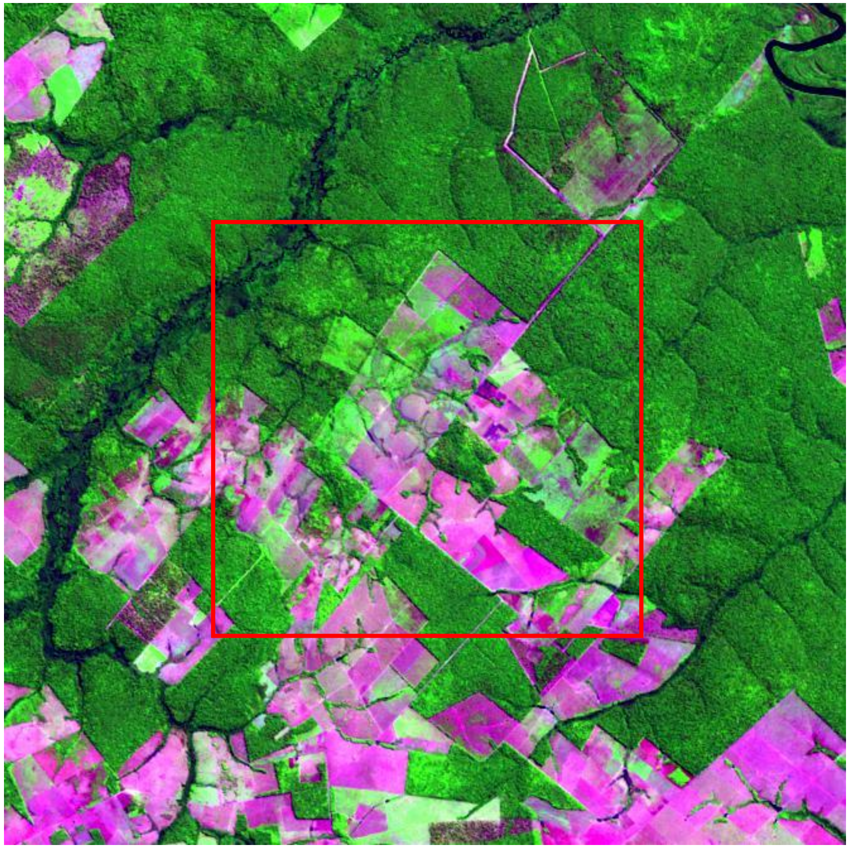
Source: JRC, Stibig et al, 2003

Example of forest cover map for insular Southeast Asia derived from 1 km SPOT VGT imagery

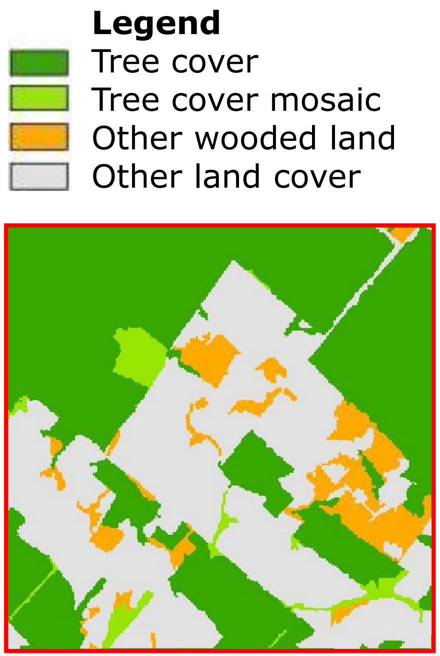


Source: JRC, Stibig et al, 2003

Example of forest cover map derived from 30 meter Landsat TM imagery over a site in Brazil



Landsat-5 TM image of 15 June 2005: 20 km x 20 km extract



Forest cover map
10 km x 10km window size
Centered at 12°S, 58°W

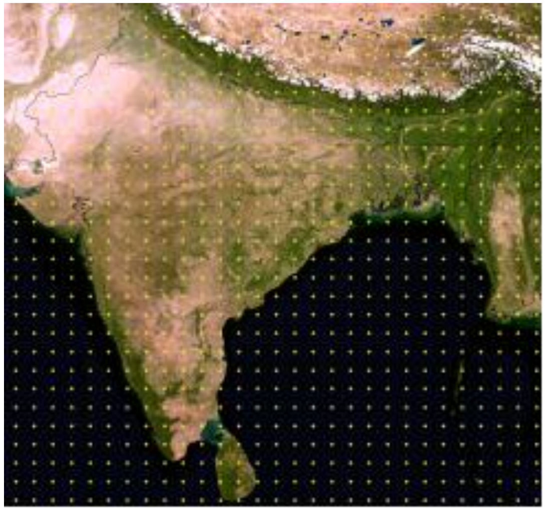
Sources: USGS 2015; Eva, et al. 2012.

Decision for wall-to-wall versus sample coverage

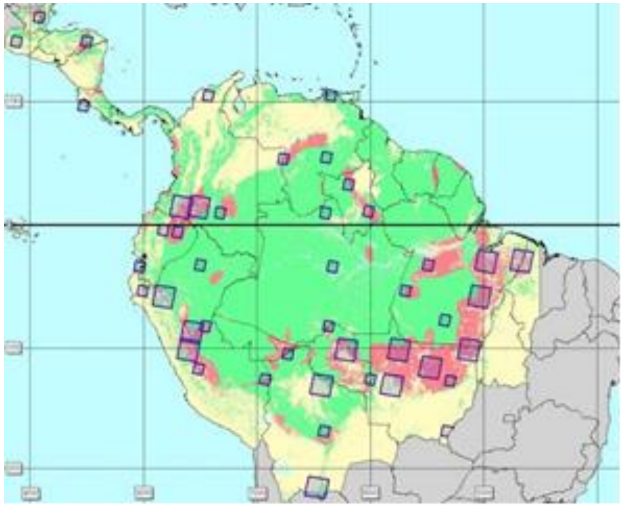
- Wall-to-wall is a common approach if appropriate for national circumstances.
- If resources are not sufficient to complete wall-to-wall coverage, sampling is more efficient for large countries and is needed to produce more accurate estimates of activity data
- Recommended sampling approaches are systematic sampling and stratified sampling. See next slide.

Systematic and stratified sampling

- Systematic sampling obtains samples on a regular interval, e.g., one every 10 km.
- Stratified samples are distributed based on proxy variables derived from coarse resolution satellite data or by combining other geo-referenced or map information.



Systematic sampling design



Stratified sampling design

Source: GOFC-GOLD Sourcebook 2013, box 2.1.2.

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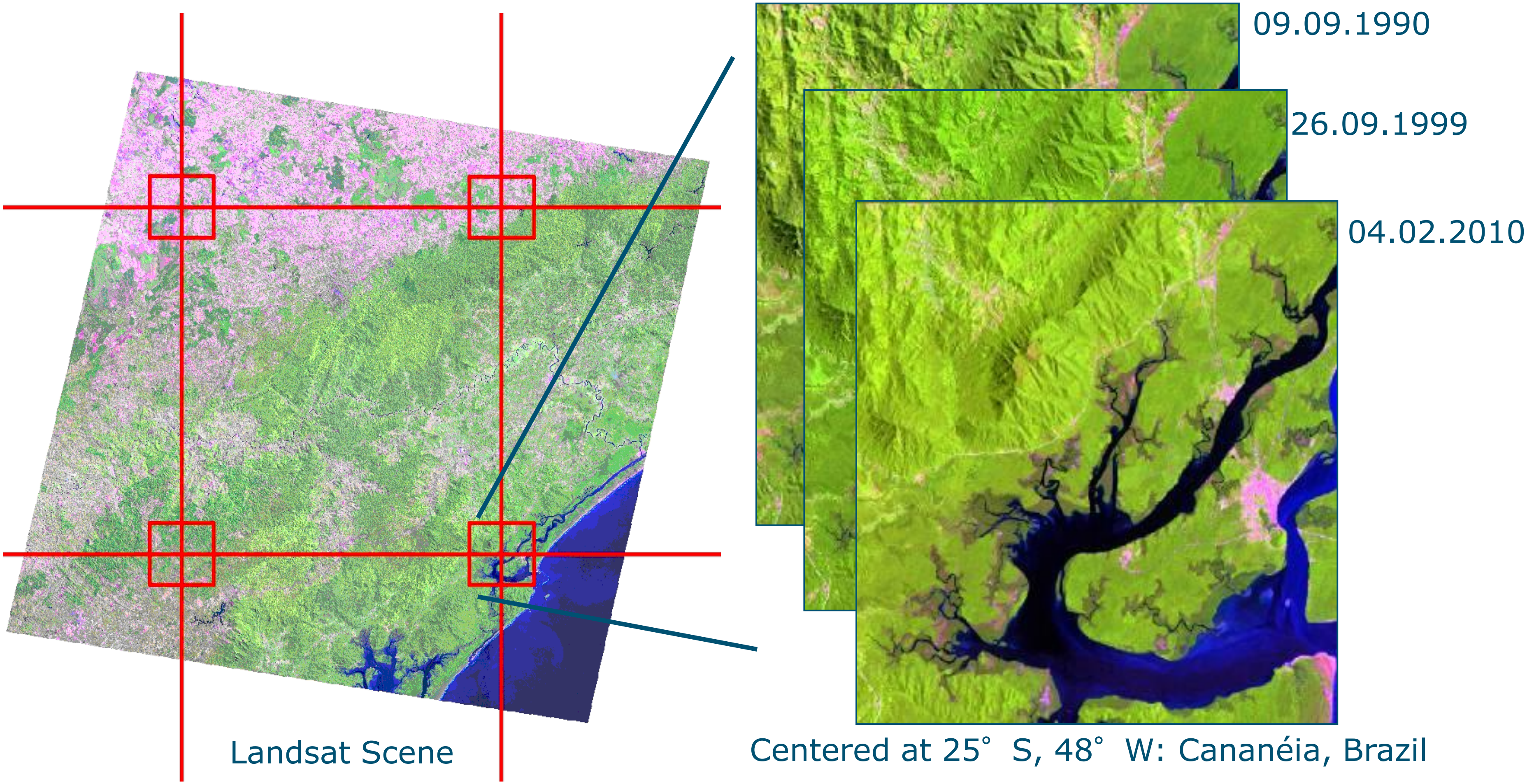
Processing of the satellite data

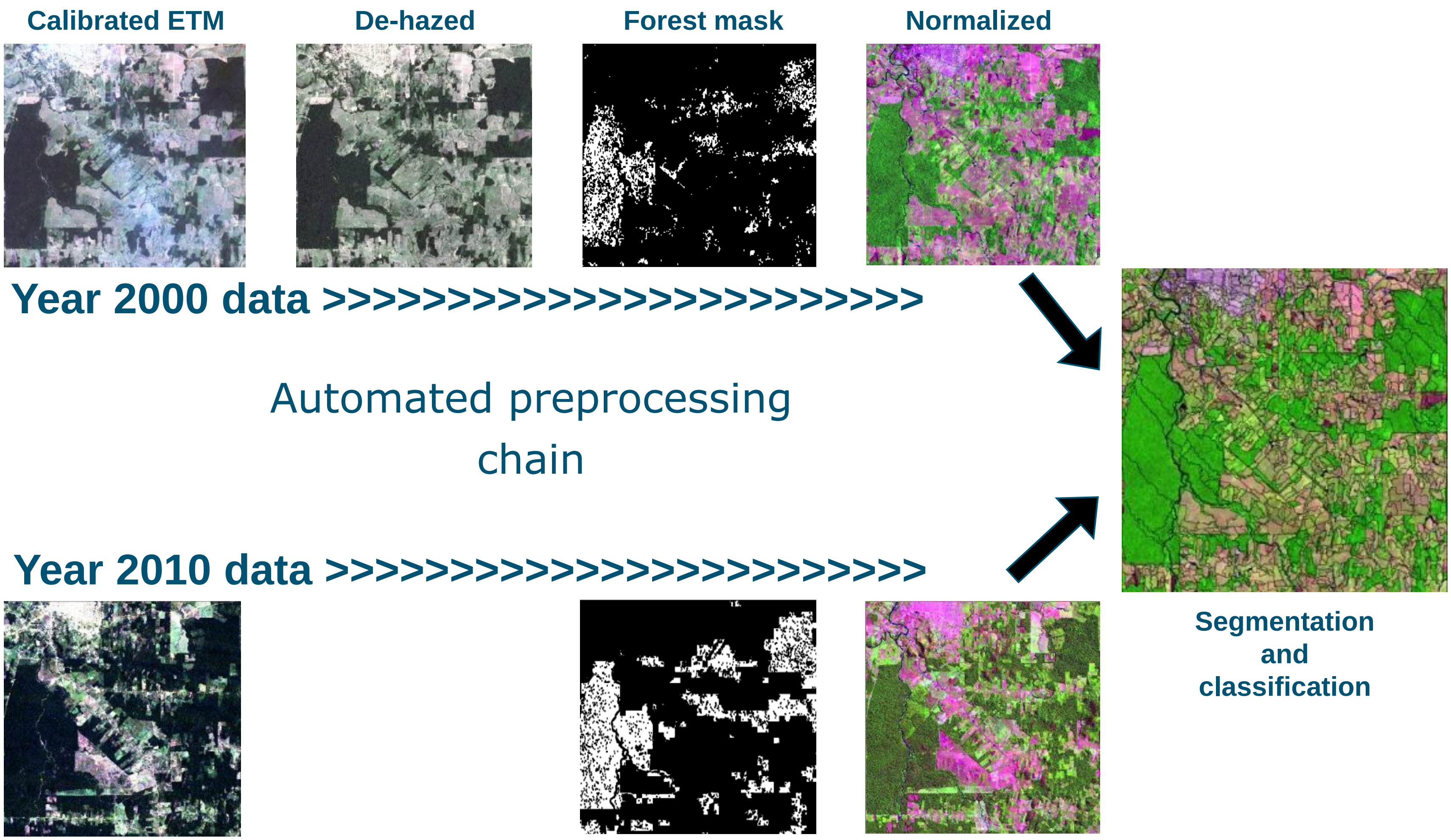
- Geometric corrections:
  - Location error should be < 1 pixel; baseline datasets (e.g.; GLS) can be used as alterative to GCPs or image-to-image registration
- Cloud and cloud shadow masking:
  - Automated or visual methods to ensure meaningfulness of image interpretation
- Radiometric corrections:
  - Depend on the used image interpretation method, not needed for visual single scene interpretation but crucial for automated multitemporal analysis

Geometric correction: example of the use of GLS dataset for image-to-image co-registration



Source: USGS 2015, GLS dataset.

Radiometric and atmospheric correction: Example of the EC Joint Research Centre automated preprocessing chain



Source: Bodart et al. 2011.

Analyzing the satellite data

- The selection of the image interpretation method depends on available resources.
- Whichever method is selected, the results should be repeatable by different analysts.
- Even in a fully automated process, visual inspection of the result by an analyst familiar with the region should be carried out to ensure appropriate interpretation.
- The main types of available methods for ~30 m resolution datasets are listed on the next slide, and a few important aspects of selected approaches are highlighted in the following slides.

Main analysis methods for moderate resolution (~ 30 m) imagery

Method for delineation	Method for class labeling	Practical minimum mapping unit	Principles for use	Advantages / limitations
Point interpretation (points sample)	Visual interpretation	< 0.1 ha	- multiple date preferable to single date interpretation - On screen preferable to printouts interpretation	- closest to classical forestry inventories - very accurate although interpreter dependent - no map of changes
Visual delineation (full image)	Visual interpretation	5 – 10 ha	- multiple date analysis preferable - On screen digitizing preferable to delineation on printouts	- easy to implement - time consuming - interpreter dependent
Pixel based classification	Supervised labeling (with training and correction phases)	<1 ha	- selection of common spectral training set from multiple dates / images preferable - filtering needed to avoid noise	- difficult to implement - training phase needed
	Unsupervised clustering + Visual labeling	<1 ha	- interdependent (multiple date) labeling preferable - filtering needed to avoid noise	- difficult to implement - noisy effect without filtering
Object based segmentation	Supervised labeling (with training and correction phases)	1 - 5 ha	- multiple date segmentation preferable - selection of common spectral training set from multiple dates / images preferable	- more reproducible than visual delineation - training phase needed
	Unsupervised clustering + Visual labeling	1 - 5 ha	- multiple date segmentation preferable - interdependent (multiple date) labeling of single date images preferable	- more reproducible than visual delineation

Source: GOFC-GOLD Sourcebook 2013, table 2.1.3.

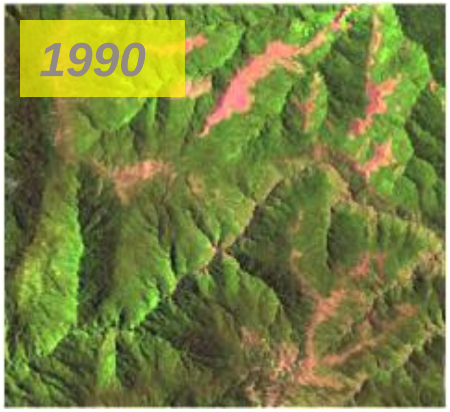
Visual delineation of land entities

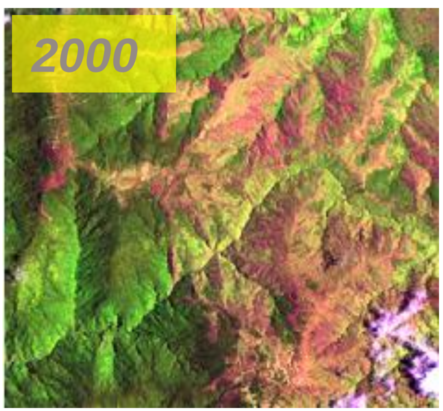
- Visual delineation of land entities is a viable approach for forest-area monitoring, particularly if image analysis tools and experiences are limited.
- The visual delineation of land entities on printouts (used in former times) is not recommended; on screen delineation should be preferred as producing directly digital results.
- When land entities are delineated visually, they should also be labeled visually.

Multidate image segmentation

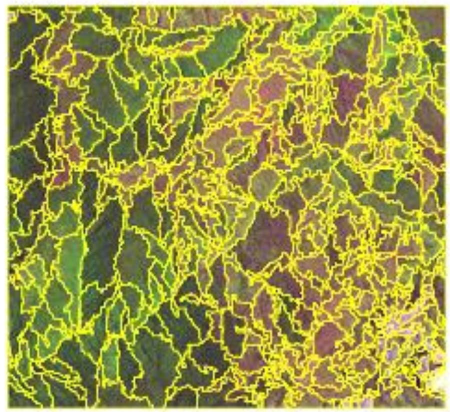
- Automated segmentation reduces processing time and increases detail.
- It is objective and repeatable.
- It delineates changed areas as separate segments.
- Ideally, analysis process would include:
    i. Multidate image segmentation on image pairs
    ii. Training area/class signature selection
    iii. Supervised clustering of individual images
    iv. Visual verification and potential editing

Example of semi-automatic multi-date segmentation and change labeling

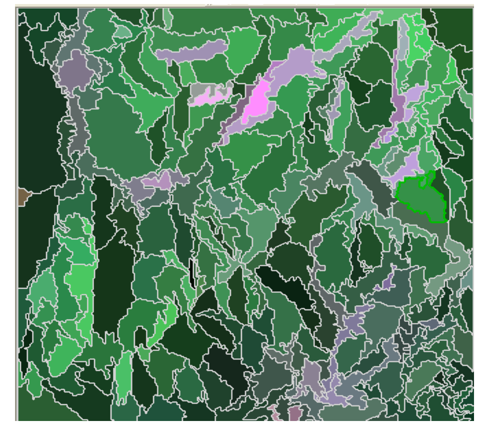




Paired segmentation



Automatic change label



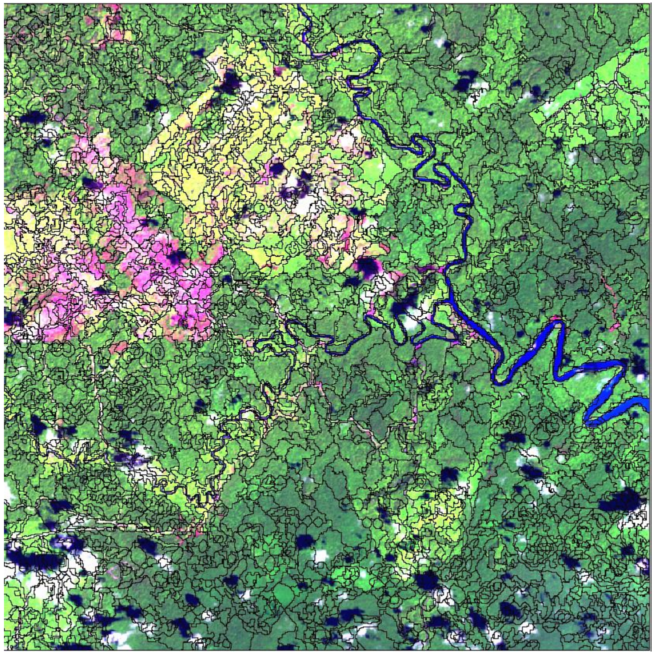
Sources: USGS 2015, GLS dataset; Bodart et al. 2011; and Raši et al. 2011.

Digital classification of image segments

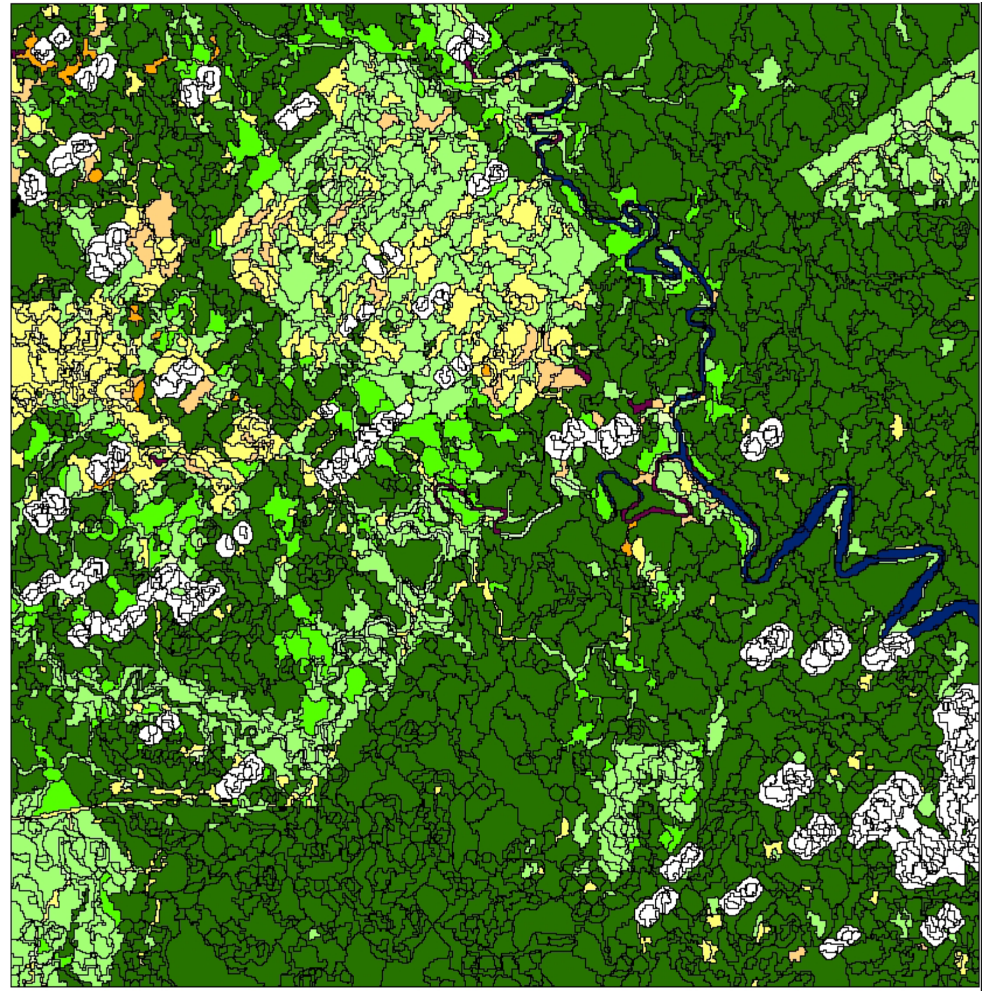
- Digital/automatic classification applies only in the case of automatically delineated segments.
- Two supervised object classifications run separately on the two multidate images are recommended instead of a single supervised object classification on the image pair.
- A common predefined standard training data set of spectral signatures for each type of ecosystem should ideally be used to create initial automated forest maps.
- Supervised classification approaches are considered more efficient in the case of a large number of images than unsupervised clustering techniques.

Example of automatic classification using signature database

a)



b)



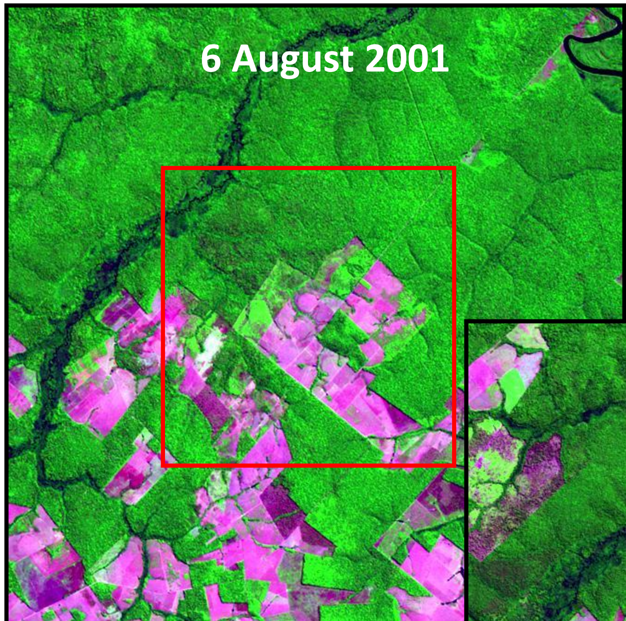
a) Multitemporal segmentation (2000–2010)

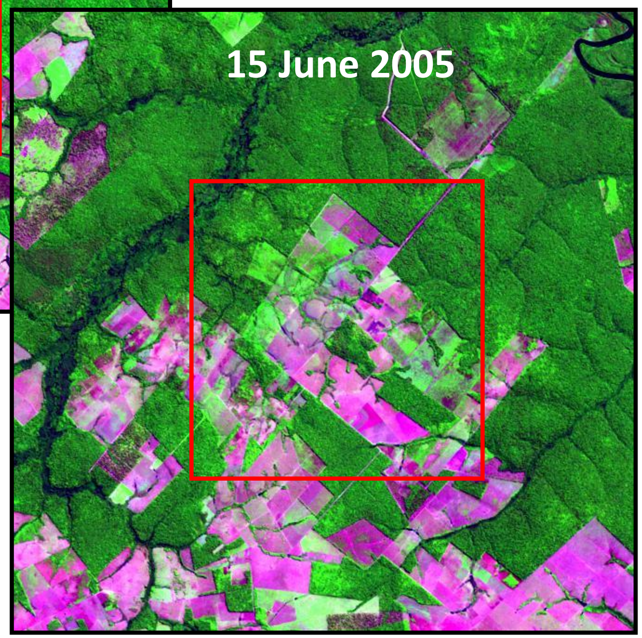
b) Automated classification of the year 2000 Landsat image based on signature database

Sources: USGS 2015, GLS dataset; Bodart et al. 2011; and Raši et al. 2011.

Legend
- Tree cover
- Shrub and regrowth
- Grass, herbaceous

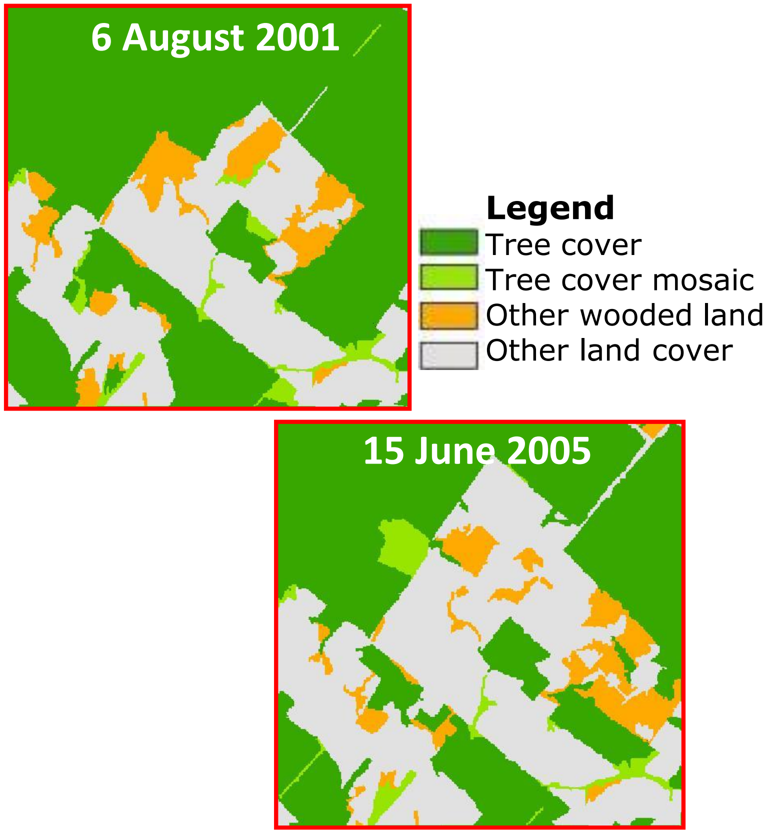
Example of forest cover change derived from Landsat TM imagery over a site in Brazil





Landsat-5 TM imagery

Land cover maps of 2001 to 2005



Sources: USGS 2015, GLS dataset; Eva et al. 2012.

Visual verification

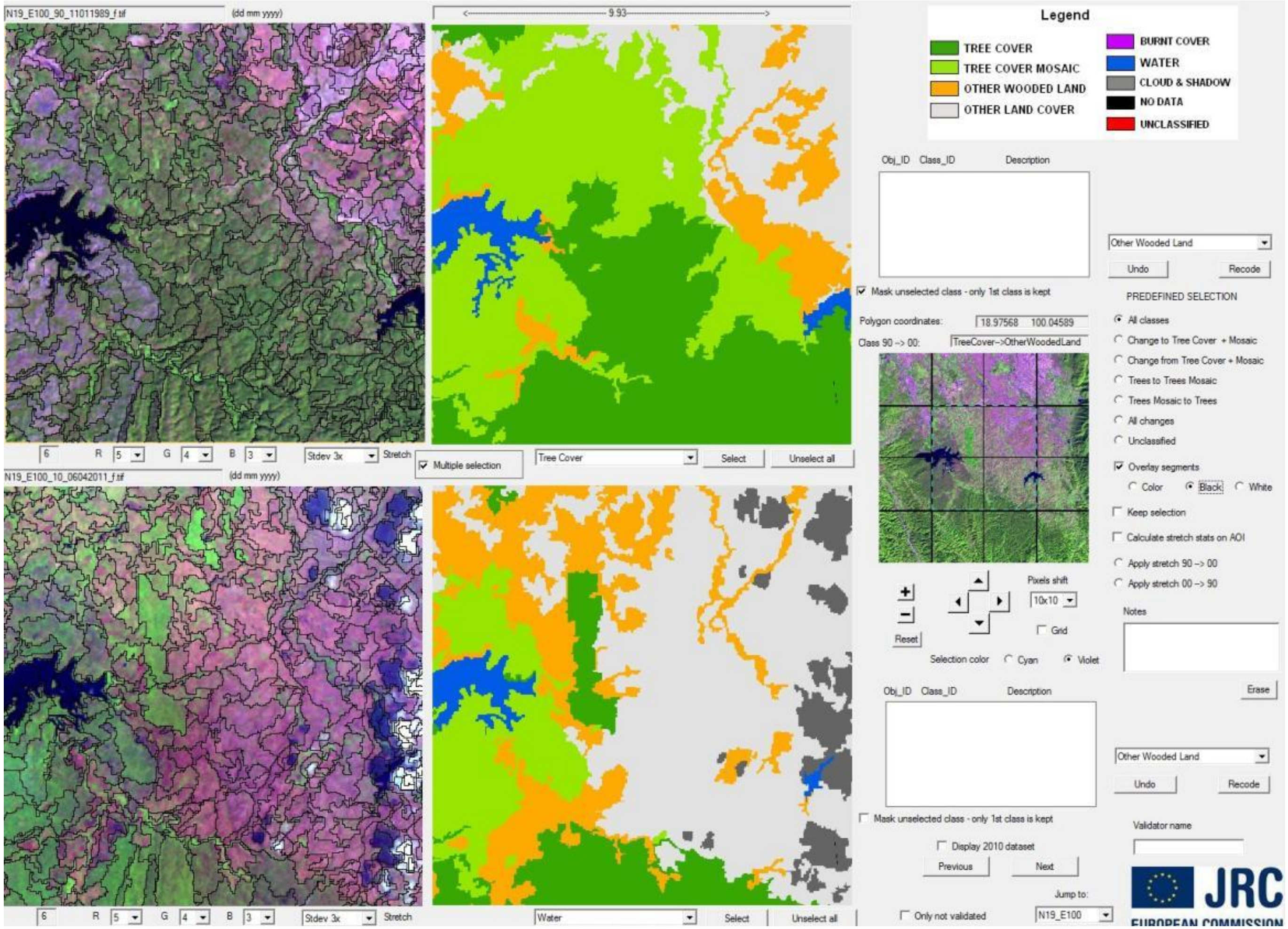
- Visual verification (or classification) is indispensable.
- Verification should take advantage of image pairs.
- Existing maps may be used as support.
- Single image pairs are preferred over image mosaics.
- Spectral, spatial, and temporal (seasonality) characteristics of the forests have to be considered.

Example of visual validation of the automated JRC-FAO assessment results

Expert validation with tailored validation Tool

Visual Control and Interpretation of automated mapping

Source: USGS 2015, GLS dataset; JRC; Simonetti et al. 2011



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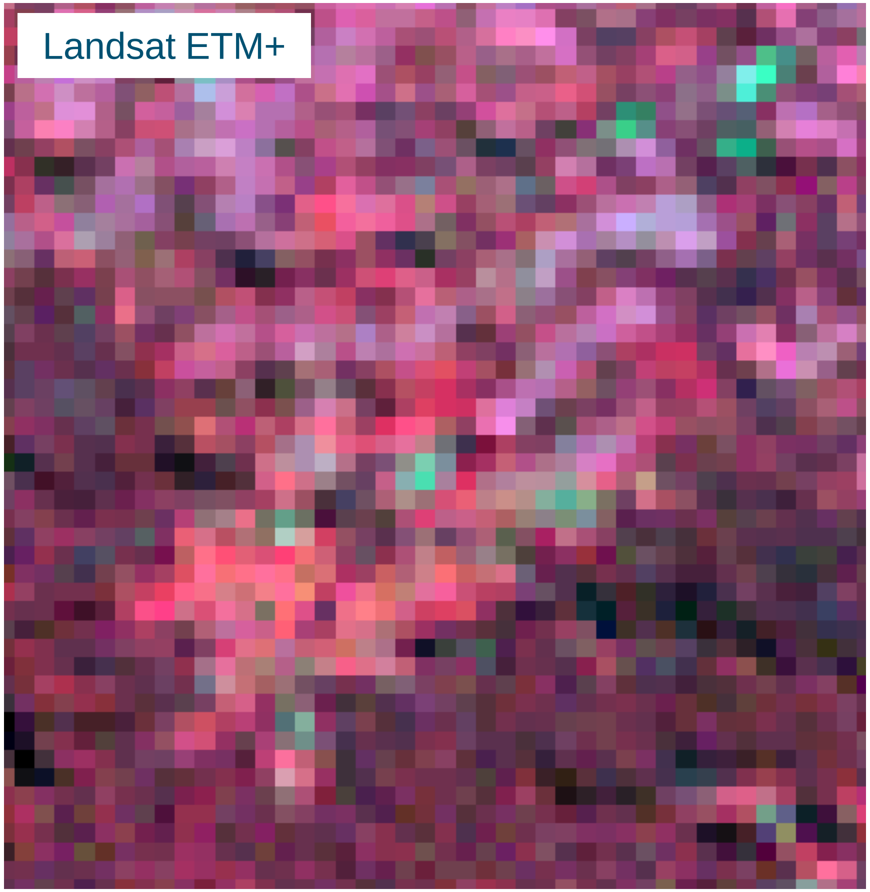
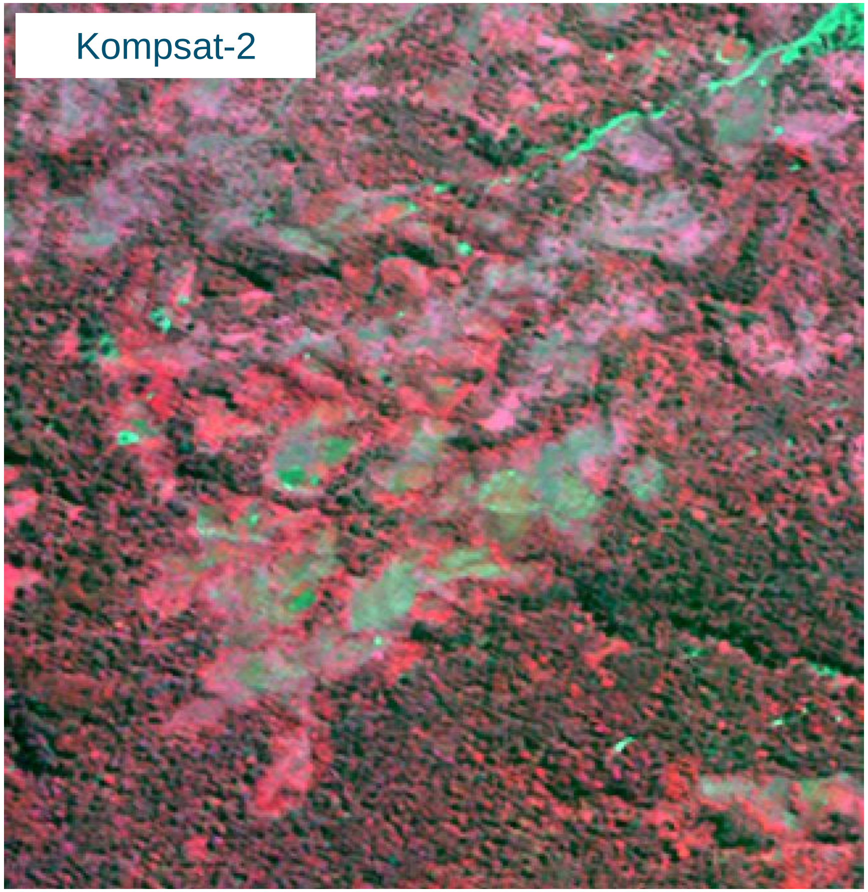
Basic concepts of an accuracy assessment

- Reporting accuracy and verification of results are essential components of a monitoring system.
- Accuracy assessment should be based on higher quality data, e.g., *in-situ* observations or analysis of very high resolution aircraft or satellite data.
- Attention needs to be given to the timing of the reference dataset, so that it matches temporally to the dataset that has been used for the forest cover mapping.
- Ideally, a statistically valid sampling procedure should be used to determine accuracy; this should lead to quantitative description of the uncertainty of the forest area estimates.

Example of the usability of very high resolution imagery for accuracy assessment

LANDSAT 30 m versus Kompsat-2 4 m resolution (RGB: NIR-R-G)





Source: USGS 2015, GLS dataset; ESA/JRC TropForest project (Kompsat).

Considerations for reporting

- Since areas of land-cover change are significant drivers of emissions, providing the best possible estimates of these areas are critical.
- It is possible to use the results of a rigorous accuracy assessment to adjust area estimates and to estimate the uncertainties for the areas for each class.
- If a statistical approach is not achievable, information obtained through other means can be used to understand the accuracy of the map. Such information may include:
    - Comparisons to other maps
    - Systematic review and judgment by local experts
    - Comparisons to nonspatial statistics

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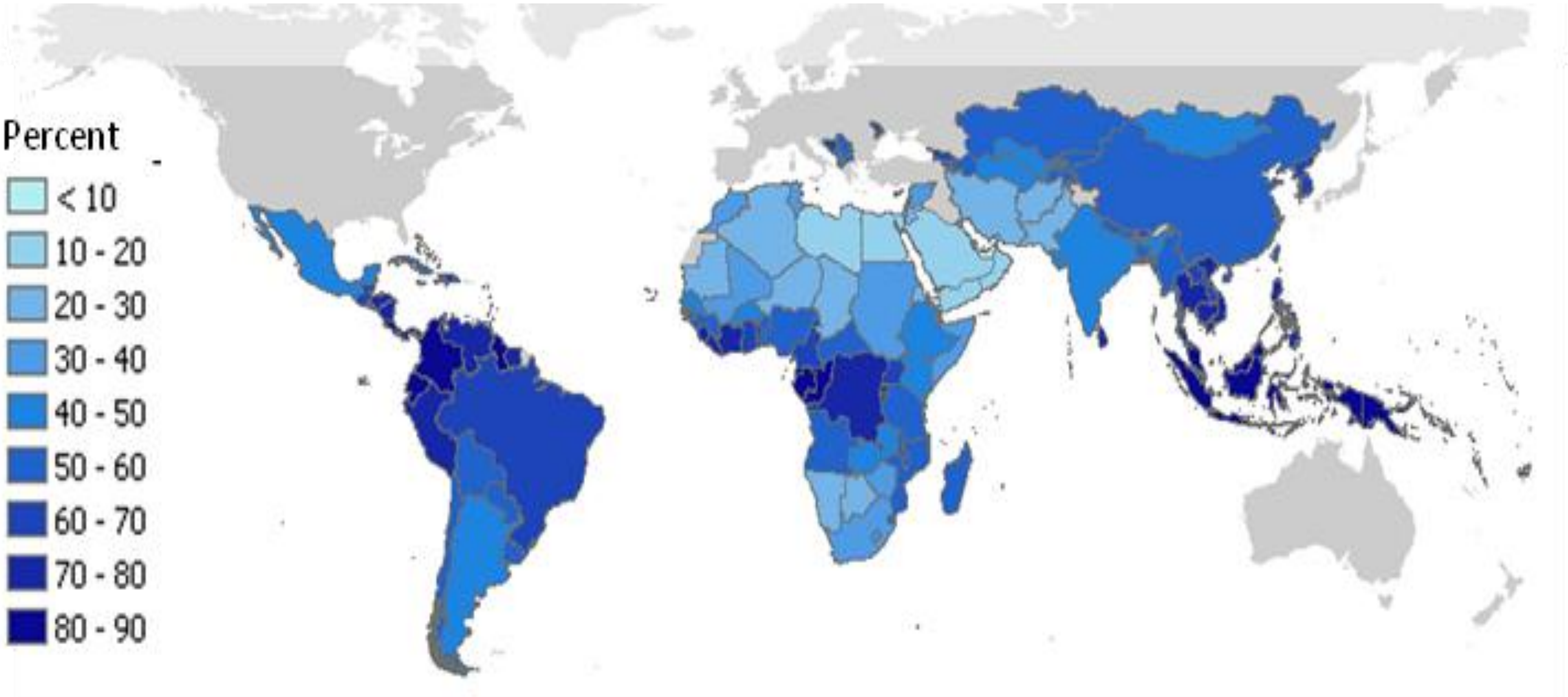
Major sources of limitations

- Clouds and cloud shadows
- Other atmospheric effects (e.g., haze and smoke)
- Effect of topography on reflectance
- Insufficient observation frequency (e.g., humid tropics)
- Scarcity of historical data
- Tradeoff between spatial resolution and coverage
- Problems of intersensor comparability (e.g., in historical time series)

Major sources of limitations: Cloud cover

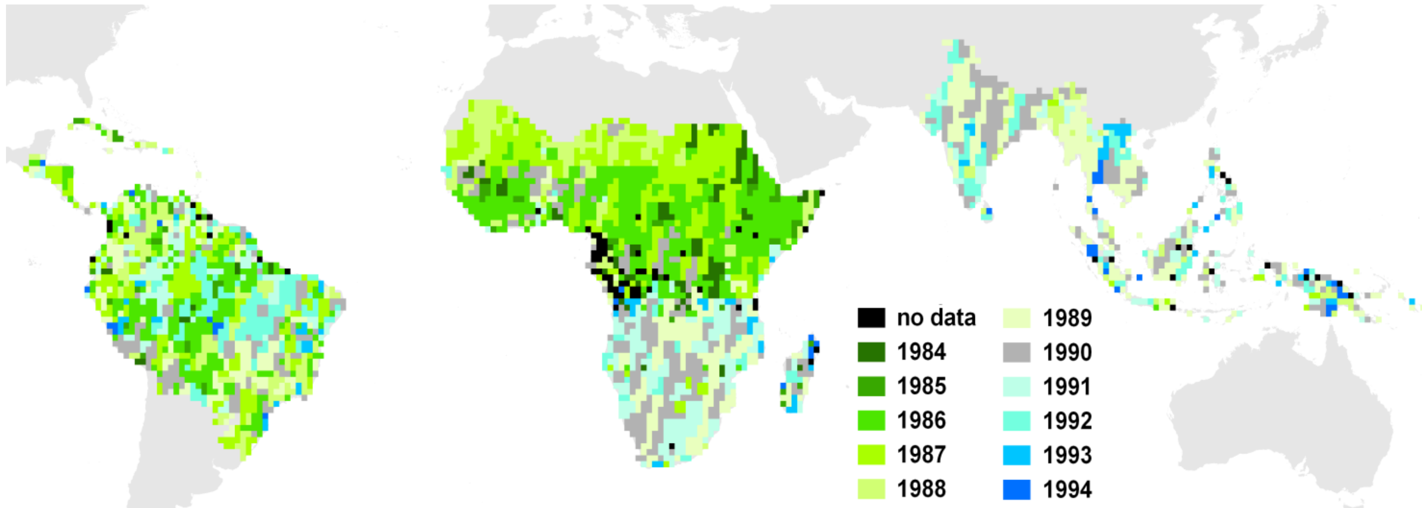


Mean annual cloud cover based on MODIS M3 Product (Cloud Fraction Mean) and EECRA (Extended Edited Cloud Report Archive)

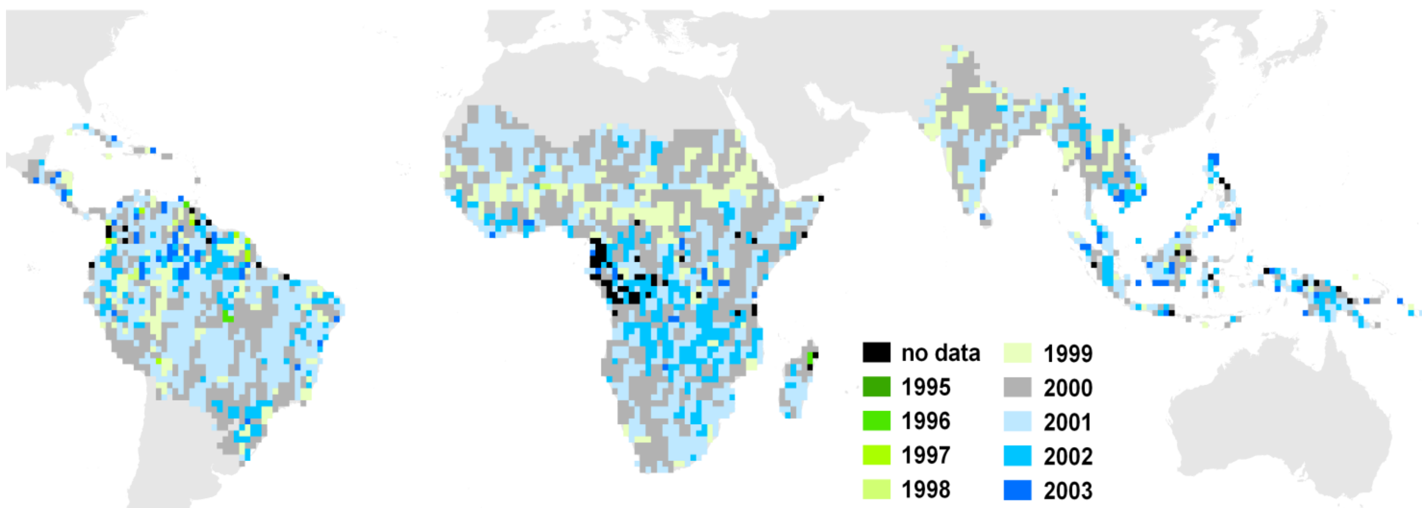
Source: Herold 2009.

Major sources of limitations: Scarcity of historical data

Actual acquisition year for target year 1990



Actual acquisition year for target year 2000



Source: JRC; Beuchle et al. 2011

In summary

- The IPCC guidance and UNFCCC decisions provide general guidelines that should be used to develop national forest definitions and monitoring approaches for REDD+ activities.
- Numerous remote sensing data and methods can be used to monitor activity data for forests, preferably with:
  - Multidate image analysis to detect changes
  - Supervised, repeatable classification approaches
  - Visual verification and rigorous accuracy assessment of the resulting maps
- Even with the limitations of satellite observation, remote sensing is indispensable for monitoring activity data for forests in tropical countries.

Country examples and exercises

Country examples

- Brazil (PRODES deforestation monitoring program)
- India (FSI: The Forest Survey of India)
- Democratic Republic of the Congo (JRC-FAO Systematic sampling)

Exercises

- Using Landsat time series data to derive forest area change estimates

Recommended modules as follow up

- Module 2.2 to proceed with monitoring activity data for forests remaining forests (incl. forest degradation)
- Module 2.8 for overview and status of evolving technologies, including, for example, radar data
- Modules 3.1 to 3.3 to learn more about REDD+ assessment and reporting

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